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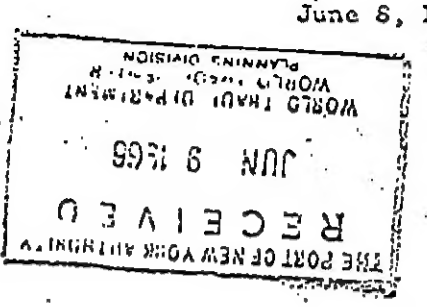


Mr. Malcolm P. Levy, Chief
World Trade Center, Planning Division
The Port of New York Authority
Room 300
111 Eighth Avenue at 15th Street
New York, New York 10011

THE WORLD TRADE CENTER --
STUDY OF STACK EFFECTS AND RELATED PROBLEMS

Dear Mr. Levy:

This letter constitutes our proposal to undertake studies to assist you in planning for the World Trade Center as discussed during our meeting at the Port Authority on May 17.

The separate tasks in these studies deal with the following problems which the Port Authority has identified as:

I Stack Effect
II Window Rupture Hazard
III Column Temperature Stability

An appraisal of sealant performance was discussed at our meeting as a fourth task, but Mr. DiPaolo's letter of May 31 indicates that the Port Authority has deferred this study for the present.

The above three tasks will be conducted concurrently, and we recommend that a single contract be set up authorizing us to initiate studies on all three. The individual tasks and anticipated results are outlined in the following sections. In general, the approach will be to examine the problems in sufficient detail to offer suggestions for possible solutions.

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TASK I. STUDY OF STACK EFFECT

In cold weather, the stack effect resulting from the difference in density of warm inside air and cold outside air can cause appreciable pressure differentials between the interior of the towers and the ambient atmospheric air. This differential, coupled with infiltration and exfiltration through walls or other openings, produces air flow up through the building within elevator shafts and stairways. High air flows cause objectionable drafts (with resulting noise) around elevator and stairwell doors and affect loads on the HVAC system. High pressure differentials can make it difficult for occupants to open doors manually. If the World Trade Center is to be functionally satisfactory, the pressure differences and air flow vertically through the towers must not be excessive.

The pressure differentials and air flows can be described as follows. At the lower levels, pressure within the tower is below atmospheric air pressure. This tends to reduce air flow out through exhaust paths (vents, spill ducts, etc.) and to increase air flow into the tower by crack infiltration and through various openings, including fresh air intakes in the building towers. The net effect is for excessive quantities of air to enter the lower levels of the building from the outdoors. At the upper levels, pressure within the towers is higher than atmospheric pressure and the situation is reversed, with the net effect being excessive air flow out of the building.

This results in a potential for flow upward through the building. The magnitude of this flow and the related pressure drop across openings within the tower will be dependent upon flow characteristics of all flow paths. Of the possible flow paths, those through the HVAC system are the most difficult to evaluate because of the modulation of control dampers.

A number of factors which affect the magnitude of the stack flow and the pressure differentials within the building include:

(1) exterior-wall leakage

(2) HVAC system operation, and

(3) wind.

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A preliminary study of stack effect conducted by Battelle for the Port Authority (reported in a letter to you dated August 31, 1965) considered only item 1 above for an assumed value of exterior wall leakage. However, the report called attention to the importance of item 2, the HVAC system with intake and exhausts open to the outside, and item 3, wind.

The previous Battelle study, at the request of the Port Authority did not take into account the interaction between the HVAC system and the stack effect. But, the operation of the HVAC system can have a significant effect on stack effect problems and in fact, can intensify stack effect or be used to overcome stack effect. Therefore, a detailed study of the HVAC system's operation on a zero F day will be crucial to the new investigation. Among the factors which must be considered are operation of HVAC controls and dampers, flow through controlled and uncontrolled ducts on days when the system is unbalanced, HVAC system pressure losses for balanced and unbalanced conditions, and building air leakage rates through HVAC louvers.

Wind can also contribute to stack effect and present additional problems in maintaining environmental control. Wind effects will be different at different levels and can add an additional component to the stack flow.

## Objectives

Studies of the stack effect and wind effect in the World Trade Center will be undertaken to determine:

(1) Pressure differentials at critical locations throughout the building (especially across doors and elevators).

(2) Air flows and potential noise resulting from pressure differentials.

(3) The effect of stack flow and pressure differentials on the use of elevators.

(4) Interaction between the HVAC system and pressures in the building.

(5) The ability of occupants to use doors and elevators subjected to the pressure differentials that are predicted.

(6) Recommendations for alleviating the undesirable effects of pressure differentials.

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Criteria

The following criteria would be used in making this study:

(1) Temperature differential of 75 F between inside and outside.

(2) (a) Condition of no wind.

(b) Wind varying from 20 mph at ground level to 60 mph at top (as established by the Port Authority for these studies).

(3) Three exterior wall leakage rates for exterior wall as follows:

(a) Tight-walled building with zero leakage; leakage occurring only at HVAC louvers and other openings.

.025 CFM / SF x 7 PSF x (6 TO 10)

(b) Building with exterior wall leakage values as supplied by Port Authority based on Sakhnovsky's estimate (0.02 cfm per sq ft at 6.24 psf pressure differential).

DETERMINE LATER

(c) Building with exterior wall leakage values six times the value estimated by Sakhnovsky.

(4) Elevator door and stairway layouts according to the latest drawings supplied by the Port Authority.

(5) Air-flow areas around doors, smoke holes, and cable holes according to the data previously transmitted by the Port Authority for the Battelle report of August 31, 1965. For doors and air locks added since that report, flow areas to be supplied by Port Authority.

(6) HVAC system and controls according to details to be supplied to Battelle by Port Authority. The air-handling systems are to be assumed to be balanced for a 75 F day. However, unbalance of the system as it affects pressure differentials will be considered due to the action of stack effect and wind through the fresh-air louvers, spill-air louvers, exhaust-air louvers, and ductwork connecting the occupied zones and the outdoors at each MER floor.

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Procedure and Expected Results

The procedure to be followed in analyzing the building for each set of conditions is as follows:

(1) The building will be divided into appropriate zones for analysis -- considering HVAC zones, elevator zones, and doors across stairways.

(2) A first approximation must be made as to pressures existing in the building at various locations.

(3) Based on these assumed pressures and flow areas, air flow rates through the various openings and internal shafts can be determined, as well as pressures for the remainder of the building.

(4) The air flow rates through various openings and shafts can then be combined to give total air flow between various zones.

(5) Air flow to and from the HVAC system for each zone can be determined with assumed pressures in zones.

(6) Air flow into or out of the building through cracks and openings can be calculated based on areas and pressures.

(7) The air flow within the building must be compared to air leakage into or out of the building. If the air flows are not equal, the assumed pressures must be adjusted and this process must be started again with the second approximation. The results derived with a first approximation will aid in selecting successive assumptions, until the calculations are in reasonable balance.

The sequence will be repeated for the different conditions of interest.

Pressure differentials predicted at the key locations in the building will be summarized in the report to the Port Authority. Pressures and air flows will be assessed as to their effect on the functional aspects of the building, including the ability of occupants to open doors. Recommendations will be made as to possible solutions to the problem, and alternate solutions will be evaluated from the viewpoint of the stack effect problem.

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## TASK II

## STUDY OF WINDOW RUPTURE HAZARD

There is a potential hazard to nearby occupants in case of sudden rupture of a window in upper floors, particularly during high wind gusts in cold weather when maximum pressure differentials exist at the top of the tower. It is important to determine whether forces on an occupant may be great enough to unbalance him and eject him through the window.

### Objectives

An analytical study will be undertaken to assess:

(1) Air velocity profile in area of suddenly ruptured window.

(2) Forces tending to eject nearby occupants through the window.

(3) Time variation of critical forces.

(4) The ability of occupants to withstand or react to the sudden ejection force or unbalance created by the forces.

### Criteria

The study will be based on the following:

(1) Maximum pressure differential due to stack effect.

(2) Two values of high wind or gusts based on data from the Port Authority's wind-tunnel model studies and meteorological data (levels of wind and gusts to be selected by the Port Authority).

(3) Location and dimensions of windows (and HVAC window induction units) according to drawings supplied by the Port Authority.

(4) Several positions of occupant relative to window.

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Procedure and Expected Results

Consideration of air-flow pattern and time buildup of velocities, together with aerodynamic drag coefficients for a typical person, will permit an estimate of forces and unbalancing moment on an occupant. An appraisal will be made as to the ability of a typical occupant to withstand or react to these forces. (Results of similar studies in aircraft and body-mechanics studies in automobile crash situations will also be brought to bear in the analysis.)

Possible measures to minimize the hazard will be evaluated and recommendations will be offered. While the contemplated study will not be exhaustive, the results should enable the Port Authority to appraise the severity of the hazard and weigh corrective measures which may be recommended. A more comprehensive investigation or model study may be indicated, depending on the degree of hazard found in this initial study.

## TASK III

## COLUMN TEMPERATURE STABILITY

### A. Analytical Study

Differential expansion between the exterior and interior columns in the World Trade Center could produce serious structural problems, as well as alignment difficulties for interior partitions and floors. The Port Authority has determined that the temperature differential between inside and outside columns should be maintained within 15 F. Without some special provisions for stabilizing temperatures, the exterior columns (being in close proximity to outside weather conditions) will be cooled to temperatures below this limit.

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Objectives

A study will be undertaken to determine:

(1) The feasibility of controlling column temperature differential within 15 F by the approaches proposed by the Port Authority.

(2) Recommendations for alternate approaches, should the proposed constructions be deemed inadequate to stabilize temperatures within the desired limits.

Criteria

The following criteria would be used in this study:

(1) Columns, fireproofing, and other structural details supplied by the Port Authority

(2) Design of proposed column covers, together with conductivity of proposed insulation and fireproofing, to be supplied by the Port Authority.

(3) Exterior wall, interior wall, and air slot construction details to be supplied by the Port Authority.

(4) Water temperatures and location of piping risers and runouts to be supplied by the Port Authority.

(5) Conditions for temperature and heat transfer analysis:

(a) Temperatures: interior columns 75 F
return air 75 F
outside air 0 F

(b) Wind velocity to be selected by the Port Authority.

(c) Suction head in return air plenum to move air over columns: 0.02 inches wg (as established by the Port Authority).

(6) Battelle's appraisal of performance, longevity, and compatability of insulation materials.

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Procedure and Expected Results

A thermal analysis of the heat transfer to, from, and within the exterior columns will be undertaken to establish temperature gradients and the feasibility of temperature control by the method proposed by the Port Authority. The analysis will show expected temperatures of the exterior column for the condition assumed.

Alternative approaches will be considered and analyzed to the extent deemed appropriate, so recommendations can be made to the Port Authority. As part of the study, a simple bench-scale thermal model might also be set up to verify the most promising approaches, prior to the full-scale mock-up tests which are being considered by the Port Authority and are discussed below.

B. Mock-up Tests on Full Scale Exterior Wall and Column Section

(Planned but not included within time and budget for the studies proposed herein.)

The Port Authority has suggested a test on a full-scale mock-up of an exterior wall section to prove out the final construction with all its details. We recommend this step as a means of verifying the analytical tests by incorporating insulation and other details closely simulating the final construction, including the "as applied" properties of the fireproofing and insulation. This test further offers the opportunity of simulating the actual heat transfer coefficients more closely than possible for the analytical study.

While the primary purpose of the mock-up test would be to verify the solution to the column temperature-stability problem, it would also provide a means for determining infiltration or exfiltration rates for different pressure differentials.

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Objectives

This mock-up test would verify or determine:

(1) Column temperatures resulting from simulated inside and outside conditions.

(2) Velocity, temperature and openings for air flow (or water supply temperatures) needed to stabilize column temperatures at desired levels.

(3) Effect of pressure differentials on infiltration through the exterior wall.

Criteria

Final criteria and conditions would be agreed upon prior to undertaking this mock-up test, but they would be similar to those listed for the analytical study under Task III-A. The test section is expected to contain 2 floor sections and at least 3 columns (roughly a section 20 feet high by 10 feet wide).

Procedure

Battelle-Columbus is equipped to handle the setup and analysis of the mock-up test.

The Port Authority would provide the necessary structural design details for Battelle to fabricate the structural section comprising columns, spandrel and floors. The Port Authority would arrange for the exterior walls, glazing, and interior walls to be supplied to Battelle for installation in the mock-up. Battelle would construct and instrument a test cell suitable for simulating the desired conditions and for obtaining the needed measurements under thermal equilibrium.

We will plan to submit a separate proposal for Task III-B after we complete the preliminary analysis of the problem and identify one or more solutions that appear to be feasible for stabilizing column temperatures.

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TIME AND COSTS

We estimate that we can complete the studies for Tasks I through III in 4 to 6 months from the time the Port Authority authorizes us to proceed. While our estimate of time and costs assumes that all three tasks are initiated together, a breakdown for the individual tasks is provided below for your information as to the relative effort we expect to devote to each task.

| | Task | Est. Time | Est. Cost |
|---|---|---|---|
| I | Study of Stack Effect | 4-6 months | $19,000 |
| II | Study of Window Rupture Hazard | 2 months | 3,000 |
| III-A | Study of Column Temperature Stability | 4-5 months | 8,000 |
| III-B | Mock-up Tests on Wall and Column Section | (Not included in this proposal; estimate to be submitted later) | |
| | TOTAL | 4-6 months elapsed time | $30,000 |

These estimates are based on the assumption that necessary inputs of information will be provided by the Port Authority as needed for the studies. Our first step will be to submit a list of specific information or drawings required, but we recognize that other needs will develop as the studies progress. We understand that we should make all requests for information through Mr. F. DiPaolo of the Port Authority, even though the material may need to be originated by consultants of the World Trade Center.

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REPORTS AND LIAISON

Liaison with the Port Authority will be maintained throughout the studies. Separate written reports summarizing the results of the individual studies will be submitted at the conclusion of each of the tasks outlined.

Upon completion of all the studies, a presentation summarizing the most significant findings and recommendations will be made orally and with visual aids, if the Port Authority so desires. We recommend this step to enable the Port Authority to derive maximum use of our studies in their communication with consultants working on the World Trade Center.

* * * * * *

If you accept the proposal outlined herein, the contract can be initiated by your sending us a letter of agreement as you have for previous Battelle studies. Should you have any comments or questions on the scope of the proposed work, please contact me or Dick Barrett at Battelle-Columbus.

Sincerely,

D. W. Locklin
Associate Chief
Thermal Systems Division

DWL:jc

In triplicate

cc: Mr. F. DiPaolo